

Final Report

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Variability of Solar UV Irradiance Related to Bright Magnetic Features Observed in Call K-line

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Relationship between Lyman alpha and K-line

Report for UARS funding agency

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ABSTRACT

In this report we comment on the relationship between the Lyman alpha and Calcium K-line emission from the Sun. We firstly examine resolved Lyman alpha images (from TRACE) and resolved K-line images. We find that the Lyman alpha emission is consistent with a linear dependence on the K-line emission.

As this is in conflict with the analysis of Johannesson et al.(1995, 1998) we proceed by comparing the disk integrated Lyman alpha flux as a function of ratio between the disk integrated Mg II core and wing fluxes (Johannesson et al (1998) having previously found a linear dependence between this index and the BBSO K-line index). We find that a reasonably good fit can be obtained, however note the discrepancies which lead Johannesson et al to consider the square root relationship. We suggest an alternative interpretation of the discrepancy.

1. Introduction

The relationship between the emission and absorption in different lines caused by different solar features is interesting for two reasons: it may allow inferences to be drawn concerning the physical conditions associated with the solar phenomena; and it allows gaps in the historical record, say for the Lyman alpha flux, to be estimated from the record of the K-line flux.

The second reason is particularly important for those wavelengths which can only be observed from space and for which the historical record is thus quite short.

Previously Johannesson et al (1995, 1998) dealt with the problem of the relationship between the K-line and Lyman alpha using the BBSO K-line index and the SUSIM $\text{Ly}\alpha$ index. Since that time TRACE has been launched providing resolved Lyman alpha images suitable for a direct comparison against the BBSO resolved K-line images.

In this report we analyze the resolved images from BBSO and TRACE and conclude that there is a linear relationship between the K-line and Ly-

man alpha fluxes. We then consider the question of the the SUSIM disk integrated Lyman alpha flux and SUSIM MgII index (used as a proxy for the BBSO K-Line index) and suggest that the major nonlinearity between these two datasets can be accounted to by differences in the limb darkening profiles of the two lines.

2. Data sources

There are four sets of data used in this study: a spatially resolved Lyman alpha image from TRACE; a spatially resolved Calcium K-line image from BBSO; the disk integrated Lyman alpha flux index from SUSIM; and the (disk integrated) MgII line core to wing ratio also from SUSIM.

The TRACE 1216 nm image chosen is shown in Figure 1. It was taken at 21:06:06 (UT) on the 7th of August 1998. The active region at this time was 474 arc seconds from the center of the disk.

The K-line image (see Figure 2) was taken at BBSO at 20:44:30(UT). BBSO's Halle CaII K-line Lyot filter was used with the bandpass set to 0.6 Å.

A Wintriss camera was used to record the image. We have not calibrated this camera for absolute intensities: for our purposes it is enough that the response was linear. We also note that this is an eight bit camera. The image has been rotated so as to correspond to the TRACE image.

The disk integrated Lyman alpha flux from SUSIM is the same Lyman alpha index Johannesson et al used in their previous studies.

The SUSIM MgII (v19r3) index has changed slightly since the analysis by Johannesson et al (1998), but the changes should not affect the linear relationship found by Johannesson (we also used the SUSIM MgII index used v19 index to confirm our conclusions are a result of the change).

3. The data

3.1. Resolved images

Figures 1 and 2 are spatially resolved Lyman alpha and K-line images of the same active region at approximately the same time. We form the ordered pairs $(I_{Ly\alpha}, I_{K-line})$. Each of these pairs represent a point where the intensity of the emitted light was $I_{Ly\alpha}$ in the Lyman alpha bandpass and I_{K-line} in the K-line bandpass. Figure 3 presents this information in three forms: firstly, we have made a scatter plot of the points $(I_{Ly\alpha}, I_{K-line})$ (light blue points). In the regions where most of the points lie, the density is sufficiently high that multiple pixels have the same values of $I_{Ly\alpha}$ and I_{K-line} (remember the cameras only produce discrete values). In fact most of the pairs fall within a narrow range, and we have, therefore, overlaid contours of the log of the (smoothed) number of pairs $(I_{Ly\alpha}, I_{K-line})$ (dark blue contours). Lastly, we have found the mean value of the Lyman alpha flux as a function of the K-line flux. This last quantity is over-plotted in red on Figure 3.

We reserve a full discussion as to what this graph indicates until section 4, however at this point we will point out that this data appears to be consistent with a simple linear relationship between the K-line and Lyman alpha fluxes.

3.2. Integrated fluxes

The direct comparison between the resolved U-V and resolved K-line images needs to be considered in light of Johannesson et al's finding that their 'square root' K-line index best reproduced the Lyman alpha index.

Rather than perform a direct comparison between the Lyman alpha emission and the Calcium K-line emission we have chosen to compare the disk integrated Lyman alpha with the ratio of the disk integrated MgII core to MgII wing. The latter is a SUSIM product, which was shown by Johannesson et al (1998) to have a linear relationship with the BBSO Calcium K-line index. Doing this not only ensures the maximum overlap of data, it also removes noise associated with the fact that BBSO is located underneath an atmosphere.

For each day (or at least for each day when SUSIM made observations) we have a pair of numbers (Ly α , K-line). In Figure 4 we have plotted a scatter-plot of these points (black dots), the mean value of the Lyman alpha index as a function of the MgII index (blue line) and a straight line approximation of the blue curve. What we see is that the straight line reproduces the blue curve quite well. The scatter plot points are also reasonably well approximated: the rms fluctuations being $0.31 \times 10^{-3} \text{W/m}^2/\text{nm}$.

In Figure 5 we plotted the Lyman alpha flux (red points), and the flux value inferred from the MgII index assuming the straight line fit shown in the previous plot, as a function of time. This is qualitatively similar to the plots shown in Johannesson et al (1998), except that we have not applied a seven day smoothing filter, we have not used a square root relationship and we have used the SUSIM MgII index instead of BBSO's K-line index.

4. Results

The fit shown in Figure 5 is quite good. As stated the RMS noise is only $0.31 \times 10^{-3} \text{W/m}^2/\text{nm}$ compared with the solar cycle fluctuations of $7 \times 10^{-3} \text{W/m}^2/\text{nm}$ (or 4.4%) or the 27 day cycles of about $1 \times 10^{-3} \text{W/m}^2/\text{nm}$ (or about 30% rms). Johannesson et al found that either the large solar cycle trend or the 27 day variations could be fitted by a linear relationship, but not both. There is some evidence of this in Figure 5: the noise is

biased with the blue (fitted) curve having higher values at the peaks during the 27 day cycles than the blue $\text{Ly}\alpha$ data. The effect looks significant and might be reduced by using a square root relationship (we cannot test that with this data set as the MgII index is integrated before we have access to it). What we can say is that the effect could also be produced by differing limb darkening functions.

The latter possibility is also consistent with our finding a linear rather than square root relationship in resolved images.

5. Conclusion

We find a linear fit of the SUSIM MgII index to the SUSIM $\text{Ly}\alpha$ index is reasonably good. Given Johannesson et al's (1998) finding that the BB-SO K-line index has a linear relationship to the MgII index, we are lead to conclude that a linear relationship between the K-Line and $\text{Ly}\alpha$ fluxes cannot be ruled out.

We suggest that the types of systematic discrepancies which are observed could be due to differing limb darkening profiles.

The spatially resolved images are also consistent with a linear relationship and do not suggest a square root relationship.

REFERENCES

- Johannesson, A., Marquette, W., and Zirin, H.:
1995, *Solar Physics*, **161** 201
- Johannesson, A., Marquette, W., and Zirin, H.:
1998, *Solar Physics*, **171** 265









